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INTERNAL REPORT

TEMPERATURE MEASUREMENT WITH LEEDS AND NORTHRUP PLATINUM RESISTANCE THERMOMETER NO. 1586182

BY

Ted C. Briggs

BRANCH Fundamental Research

PROJECT NO. 4330

DATE June 1964

AMARILLO, TEXAS

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INTRODUCTION

The purpose of this report is to compile in one manuscript the constants, equations, and data necessary for measurement of temperature with Leeds and Northrup platinum resistance thermometer No. 1586182.

TEMPERATURE MEASUREMENT WITH A PLATINUM RESISTANCE THERMOMETER

The international temperature scale is based upon a number of fixed and reproducible temperatures. Specific numerical values have been assigned to these fixed points. The platinum resistance thermometer is the standard instrument for interpolations between the fixed temperature points. Specific interpolation formulas are used to calculate temperatures between the fixed points from the measured resistance of a platinum resistance thermometer.

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Work on manuscript completed June 1964.

Over the temperature range 0° to 630° C the interpolation formula to be used is the Callendar equation (1).

$$t = \frac{R_t - R_o}{\alpha R_o} + \delta\left(\frac{t}{100} - 1\right)\frac{t}{100} \qquad (1)$$

Over the temperature range 0° to -182.97° C the interpolation formula to be used is the modified Callendar equation (2).

$$t = \frac{R_t - R_o}{\alpha R_o} + \delta\left(\frac{t}{100} - 1\right)\frac{t}{100} + \beta\left(\frac{t}{100} - 1\right)\left(\frac{t}{100}\right)^3 \qquad (2)$$

For convenience the Callendar equations can be rearranged in form. For temperatures above 0° C the Callendar equation can be written as (3).

$$\frac{R_t}{R_o} = 1 + \alpha t - \alpha\delta\left(\frac{t}{100} - 1\right)\frac{t}{100} \qquad (3)$$

For temperatures below 0°C the Callendar equation can be written as (4).

$$\frac{R_t}{R_o} = 1 + \alpha t - \alpha\delta\left(\frac{t}{100} - 1\right)\frac{t}{100} - \alpha\beta\left(\frac{t}{100} - 1\right)\left(\frac{t}{100}\right)^3 \qquad (4)$$

In the Callendar equations t is the measured temperature, R_t is the resistance of the platinum resistance thermometer at temperature t; R_o is the resistance of the platinum resistance thermometer at the ice point; and α, δ, and β are calibration constants. The constants α, δ, and β are determined for each platinum resistance thermometer by calibration at fixed points, the boiling point of oxygen, the melting point of ice, the boiling point of water, and the boiling point of sulfur. Platinum resistance thermometer

No. 1586182 was calibrated and certified by Leeds and Northrup in February 1962. The Callendar equation constants for thermometer No. 1586182 are listed in table 1.

When making a number of temperature measurements with a platinum resistance thermometer it is convenient to have a table of resistance ratios $\frac{R_t}{R_o}$ computed at increments of 1° C. Resistance ratios were computed at increments of 1° C over the temperature range -183° to 200° C using the constants in table 1 and equations (3) and (4). The calculations were done using an IBM 1620 computer. Linear interpolation between one degree intervals will not introduce an error greater than 0.0001 degree at any part of the scale. The computed resistance ratios are recorded in table 3.

The constants α, δ, and β of the Callendar equation are independent of the bridge used to make a resistance measurement; however, the constant R_o is dependent upon the bridge used. To measure a temperature with a resistance thermometer one must have a reliable value of the resistance of the thermometer at some known and reproduciable fixed temperature. This fixed point is usually selected as the resistance at the ice point, and is designated as R_o. By international agreement the ice point has been defined as 0.01° C below the triple point of water.

DETERMINATION OF THE ICE POINT RESISTANCE OF THERMOMETER NO. 1586182

There are several triple point cells available in the Helium Research Center. Four of these cells were used to establish a

value for the ice point resistance R_o of platinum resistance thermometer No. 1586182. Two of the cells were commercial triple point cells. The other two cells were constructed by Research Center personnel. The resistance of the thermometer at the triple point R_T was measured on several different days. Measurements were made at intervals of from 15 to 30 minutes until the ice mantle of the triple point cell began to float. Measurements were made with a continuous current of two milliamperes flowing through the thermometer. Resistances were measured with a Leeds and Northrup G-2 Mueller bridge No. 1603629. Measurements were made with the bridge in the N and R resistance positions. The actual thermometer resistance is the average of the two readings. Calibration data for bridge No. 1603629 is listed in table 2.

Seventy three measurements of the resistance at the triple point were made. The experimental data are recorded in table 4. The average triple point resistance R_T was 25.54736 ohms. A bridge correction from table 2 of 0.00008 ohms must be subtracted to give a corrected average triple point resistance R_T of 25.54728 ohms. The standard deviation of a single experimental measurement was ±0.0003 ohms. The standard deviation of the mean of the measurements was ±0.00004 ohms. The resistance at the triple point for thermometer No. 1586182 is $R_T = 25.54728 \pm 0.00004$ absolute ohms.

From table 3 $\frac{R_T}{R_o} = 1.00003984$.

$$\therefore\ R_o = \frac{25.54728 \pm 0.00004}{1.00003984} = \underline{25.54626 \pm 0.00004 \text{ absolute ohms}}.$$

SAMPLE CALCULATION

Suppose one wishes to measure a temperature with bridge No. 1603629 and thermometer No. 1586182. Suppose the corrected resistance at the unknown temperature is $R_t = 21.4796$ ohms; then $\frac{R_t}{R_o} = \frac{21.4796}{25.54626} = 0.8408119$. From table 3 one can see that the temperature is between -39° and -40° C. A linear interpolation between these temperatures gives a temperature of -39.709° C for $R_t = 21.4796$ ohms.

TABLE 1. - Callendar equation constants for thermometer No. 1586182

Data from Leeds and Northrup certificate for platinum resistance thermometer No. 1586182. Certified in February 1962.

Approximate resistance at the ice point

R_o = 25.545 absolute ohms

Fundamental coefficient of coil

α = 0.00392612

Delta in the Callendar equation

δ = 1.492

Beta in the modified Callendar equation for subzero temperatures

β = 0.1102

The constants were determined with a current of approximately 2 milliamperes flowing through the thermometer coil and a minimum immersion of seven inches.

TABLE 2. - Dial corrections for Leeds and Northrup bridge No. 1603629

Data from Leeds and Northrup certificate for Mueller bridge No. 1603629

10 Dial Reading	10 Dial Correction	1 Dial Reading	1 Dial Correction
0	0.0000	0	0.00000
10	-0.0001	1	0.00000
20	-0.0001	2	0.00000
20.5	-0.0001	3	0.00001
30	-0.0003	4	0.00001
40	-0.0003	5	0.00001
50	-0.0004	6	0.00001
60	-0.0004	7	0.00002
70	-0.0004	8	0.00001
80	-0.0005	9	0.00001
90	-0.0006	X	0.00001
X0	-0.0007		

0.1 Dial Reading	0.1 Dial Correction	0.01 Dial Reading	0.01 Dial Correction
0.0	0.00000	0.00	0.00000
0.1	0.00000	0.01	0.00000
0.2	0.00000	0.02	0.00000
0.3	0.00000	0.03	0.00001
0.4	0.00000	0.04	0.00001
0.5	0.00000	0.05	0.00001
0.6	0.00000	0.06	0.00001
0.7	0.00000	0.07	0.00001
0.8	0.00000	0.08	0.00001
0.9	0.00000	0.09	0.00001
0.X	0.00001	0.0X	0.00001

Corrections to the 0.001 and 0.0001 dials were found to be 0.00000.

TABLE 3. - Resistance Ratios, $\frac{R_t}{R_o}$

Temperature °C	$\frac{R_t}{R_o}$	Temperature °C	$\frac{R_t}{R_o}$	Temperature °C	$\frac{R_t}{R_o}$
200	1.7735085	158	1.6149589	116	1.4543427
199	1.7697575	157	1.6111587	115	1.4504934
198	1.7660053	156	1.6073574	114	1.4466427
197	1.7622520	155	1.6035549	113	1.4427910
196	1.7584976	154	1.5997511	112	1.4389382
195	1.7547419	153	1.5959463	111	1.4350841
194	1.7509850	152	1.5921403	110	1.4312289
193	1.7472270	151	1.5883331	109	1.4273724
192	1.7434679	150	1.5845247	108	1.4235148
191	1.7397076	149	1.5807151	107	1.4196561
190	1.7359461	148	1.5769044	106	1.4157962
189	1.7321833	147	1.5730925	105	1.4119351
188	1.7284195	146	1.5692795	104	1.4080728
187	1.7246544	145	1.5654653	103	1.4042093
186	1.7208883	144	1.5616498	102	1.4003448
185	1.7171209	143	1.5578332	101	1.3964790
184	1.7133523	142	1.5540155	100	1.3926120
183	1.7095826	141	1.5501966	99	1.3887437
182	1.7058117	140	1.5463765	98	1.3848745
181	1.7020397	139	1.5425552	97	1.3810040
180	1.6982665	138	1.5387327	96	1.3771324
179	1.6944920	137	1.5349091	95	1.3732596
178	1.6907164	136	1.5310844	94	1.3693855
177	1.6869397	135	1.5272585	93	1.3655104
176	1.6831618	134	1.5234312	92	1.3616341
175	1.6793827	133	1.5196030	91	1.3577566
174	1.6756024	132	1.5157735	90	1.3538779
173	1.6718210	131	1.5119429	89	1.3499980
172	1.6680384	130	1.5081111	88	1.3461170
171	1.6642546	129	1.5042781	87	1.3422349
170	1.6604697	128	1.5004439	86	1.3383515
169	1.6566835	127	1.4966086	85	1.3344670
168	1.6528962	126	1.4927721	84	1.3305812
167	1.6491078	125	1.4889345	83	1.3266944
166	1.6453182	124	1.4850956	82	1.3228064
165	1.6415274	123	1.4812556	81	1.3189172
164	1.6377353	122	1.4774144	80	1.3150268
163	1.6339422	121	1.4735721	79	1.3111352
162	1.6301479	120	1.4697286	78	1.3072424
161	1.6263524	119	1.4658838	77	1.3033486
160	1.6225558	118	1.4620380	76	1.2994535
159	1.6187579	117	1.4581909	75	1.2955573

TABLE 3. - Resistance Ratios, $\frac{R_t}{R_o}$ (Con.)

Temperature °C	$\frac{R_t}{R_o}$	Temperature °C	$\frac{R_t}{R_o}$	Temperature °C	$\frac{R_t}{R_o}$
74	1.2916598	32	1.1269104	- 10	0.9600939
73	1.2877612	31	1.1229626	- 11	0.9560968
72	1.2838615	30	1.1190137	- 12	0.9520984
71	1.2799606	29	1.1150635	- 13	0.9480989
70	1.2760585	28	1.1111122	- 14	0.9440981
69	1.2721551	27	1.1071597	- 15	0.9400960
68	1.2682507	26	1.1032061	- 16	0.9360928
67	1.2643451	25	1.0992513	- 17	0.9320884
66	1.2604383	24	1.0952952	- 18	0.9280827
65	1.2565304	23	1.0913381	- 19	0.9240758
64	1.2526212	22	1.0873797	- 20	0.9200675
63	1.2487109	21	1.0834203	- 21	0.9160582
62	1.2447994	20	1.0794596	- 22	0.9120475
61	1.2408868	19	1.0754977	- 23	0.9080356
60	1.2369730	18	1.0715347	- 24	0.9040225
59	1.2330579	17	1.0675705	- 25	0.9000080
58	1.2291418	16	1.0636051	- 26	0.8959923
57	1.2252245	15	1.0596386	- 27	0.8919753
56	1.2213060	14	1.0556708	- 28	0.8879571
55	1.2173863	13	1.0517020	- 29	0.8839376
54	1.2134654	12	1.0477319	- 30	0.8799166
53	1.2095434	11	1.0437607	- 31	0.8758945
52	1.2056202	10	1.0397883	- 32	0.8718711
51	1.2016959	9	1.0358147	- 33	0.8678464
50	1.1977704	8	1.0318400	- 34	0.8638204
49	1.1938436	7	1.0278641	- 35	0.8597929
48	1.1899157	6	1.0238870	- 36	0.8557642
47	1.1859867	5	1.0199088	- 37	0.8517342
46	1.1820565	4	1.0159293	- 38	0.8477029
45	1.1781251	3	1.0119487	- 39	0.8436702
44	1.1741925	2	1.0079670	- 40	0.8396360
43	1.1702588	1	1.0039840	- 41	0.8356006
42	1.1663239	0	1.0000000	- 42	0.8315639
41	1.1623878	- 1	0.9960147	- 43	0.8275257
40	1.1584506	- 2	0.9920283	- 44	0.8234862
39	1.1545121	- 3	0.9880406	- 45	0.8194452
38	1.1505725	- 4	0.9840519	- 46	0.8154029
37	1.1466318	- 5	0.9800618	- 47	0.8113592
36	1.1426899	- 6	0.9760706	- 48	0.8073141
35	1.1387468	- 7	0.9720783	- 49	0.8032676
34	1.1348024	- 8	0.9680847	- 50	0.7992195
33	1.1308570	- 9	0.9640900	- 51	0.7951701

TABLE 3. - Resistance Ratios, $\frac{R_t}{R_o}$ (Con.)

Temperature °C	$\frac{R_t}{R_o}$	Temperature °C	$\frac{R_t}{R_o}$	Temperature °C	$\frac{R_t}{R_o}$
- 52	0.7911193	- 94	0.6195654	-136	0.4446781
- 53	0.7870670	- 95	0.6154437	-137	0.4404653
- 54	0.7830133	- 96	0.6113202	-138	0.4362500
- 55	0.7789580	- 97	0.6071948	-139	0.4320322
- 56	0.7749014	- 98	0.6030676	-140	0.4278117
- 57	0.7708433	- 99	0.5989384	-141	0.4235888
- 58	0.7667836	-100	0.5948071	-142	0.4193634
- 59	0.7627225	-101	0.5906740	-143	0.4151353
- 60	0.7586598	-102	0.5865389	-144	0.4109046
- 61	0.7545956	-103	0.5824019	-145	0.4066712
- 62	0.7505300	-104	0.5782629	-146	0.4024353
- 63	0.7464628	-105	0.5741218	-147	0.3981967
- 64	0.7423940	-106	0.5699787	-148	0.3939555
- 65	0.7383237	-107	0.5658336	-149	0.3897115
- 66	0.7342518	-108	0.5616865	-150	0.3854648
- 67	0.7301784	-109	0.5575373	-151	0.3812154
- 68	0.7261034	-110	0.5533860	-152	0.3769632
- 69	0.7220268	-111	0.5492327	-153	0.3727083
- 70	0.7179485	-112	0.5450772	-154	0.3684506
- 71	0.7138688	-113	0.5409197	-155	0.3641900
- 72	0.7097873	-114	0.5367600	-156	0.3599267
- 73	0.7057043	-115	0.5325981	-157	0.3556606
- 74	0.7016196	-116	0.5284341	-158	0.3513916
- 75	0.6975332	-117	0.5242680	-159	0.3471197
- 76	0.6934452	-118	0.5200996	-160	0.3428448
- 77	0.6893556	-119	0.5159291	-161	0.3385671
- 78	0.6852643	-120	0.5117563	-162	0.3342865
- 79	0.6811713	-121	0.5075813	-163	0.3300029
- 80	0.6770764	-122	0.5034041	-164	0.3257163
- 81	0.6729800	-123	0.4992246	-165	0.3214266
- 82	0.6688819	-124	0.4950428	-166	0.3171341
- 83	0.6647820	-125	0.4908586	-167	0.3128385
- 84	0.6606803	-126	0.4866723	-168	0.3085398
- 85	0.6565769	-127	0.4824836	-169	0.3042381
- 86	0.6524717	-128	0.4782926	-170	0.2999331
- 87	0.6483648	-129	0.4740992	-171	0.2956252
- 88	0.6442561	-130	0.4699034	-172	0.2913141
- 89	0.6401455	-131	0.4657052	-173	0.2869999
- 90	0.6360331	-132	0.4615047	-174	0.2826825
- 91	0.6319189	-133	0.4573017	-175	0.2783618
- 92	0.6278029	-134	0.4530964	-176	0.2740380
- 93	0.6236851	-135	0.4488884	-177	0.2697109

TABLE 3. - Resistance Ratios, $\frac{R_t}{R_o}$ (Con.)

Temperature °C	$\frac{R_t}{R_o}$
-178	0.2653806
-179	0.2610470
-180	0.2567101
-181	0.2523698
-182	0.2480263
-183	0.2436794

TABLE 4. - Resistance of thermometer No. 1586182 at the triple point of water

5/20/64 Bureau of Mines triple point cell - Thermodynamics Section

Bridge Reading

N	Deviation from Average	R	Deviation from Average
25.5488	+0.0006	25.5471	+0.0006
25.5488	+0.0006	25.5470	+0.0005
25.5487	+0.0005	25.5468	+0.0003
25.5485	+0.0003	25.5468	+0.0003
25.5485	+0.0003	25.5467	+0.0002
25.5483	+0.0001	25.5465	0.0000
25.5482	0.0000	25.5465	0.0000

5/21/64 Bureau of Mines triple point cell - Thermodynamics Section

Bridge Reading

N	Deviation from Average	R	Deviation from Average
25.5481	-0.0001	25.5464	-0.0001
25.5481	-0.0001	25.5464	-0.0001
25.5480	-0.0002	25.5463	-0.0002
25.5479	-0.0003	25.5463	-0.0002
25.5480	-0.0002	25.5463	-0.0002

Bridge Reading

N	Deviation from Average	R	Deviation from Average
25.5479	-0.0003	25.5462	-0.0003
25.5479	-0.0003	25.5463	-0.0002
25.5479	-0.0003	25.5463	-0.0002
25.5479	-0.0003	25.5462	-0.0003

TABLE 4. - Resistance of thermometer No. 1586182 at the triple point of water (Con.)

5/22/64 Trans-Sonics triple point cell No. 1 - Physical Properties Section

Bridge Reading			
N	Deviation from Average	R	Deviation from Average
25.5477	-0.0005	25.5460	-0.0005
25.5477	-0.0005	25.5460	-0.0005
25.5477	-0.0005	25.5460	-0.0005
25.5478	-0.0004	25.5460	-0.0005

Bridge Reading			
N	Deviation from Average	R	Deviation from Average
25.5477	-0.0005	25.5460	-0.0005
25.5478	-0.0004	25.5460	-0.0005
25.5477	-0.0005	25.5460	-0.0005
25.5477	-0.0005	25.5460	-0.0005
25.5477	-0.0005	25.5460	-0.0005
25.5477	-0.0005	25.5460	-0.0005

5/25/64 Bureau of Mines triple point cell - Physical Properties Section

Bridge Reading			
N	Deviation from Average	R	Deviation from Average
25.5482	0.0000	25.5466	+0.0001
25.5481	-0.0001	25.5465	0.0000
25.5481	-0.0001	25.5465	0.0000
25.5481	-0.0001	25.5465	0.0000
25.5480	-0.0002	25.5464	-0.0001
25.5480	-0.0002	25.5464	-0.0001
25.5480	-0.0002	25.5464	-0.0001
25.5480	-0.0002	25.5464	-0.0001
25.5479	-0.0003	25.5464	-0.0001

TABLE 4. - Resistance of thermometer No. 1586182 at the triple point of water (Con.)

5/26/64 Trans-Sonics triple point cell No. 1 - Physical Properties Section

	Bridge Reading		
N	Deviation from Average	R	Deviation from Average
25.5485	+0.0003	25.5468	+0.0003
25.5486	+0.0004	25.5469	+0.0004
25.5485	+0.0003	25.5468	+0.0003
25.5486	+0.0004	25.5467	+0.0002
25.5485	+0.0003	25.5468	+0.0003
25.5485	+0.0003	25.5468	+0.0003
25.5483	+0.0001	25.5466	+0.0001
25.5483	+0.0001	25.5466	+0.0001
25.5482	0.0000	25.5465	0.0000
25.5482	0.0000	25.5465	0.0000
25.5481	-0.0001	25.5465	0.0000

5/27/64 Trans-Sonics triple point cell No. 1 - Physical Properties Section

	Bridge Reading		
N	Deviation from Average	R	Deviation from Average
25.5477	-0.0005	25.5462	-0.0003
25.5479	-0.0003	25.5463	-0.0002
25.5478	-0.0004	25.5462	-0.0003
25.5479	-0.0003	25.5463	-0.0002
25.5480	-0.0002	25.5465	0.0000
25.5480	-0.0002	25.5465	0.0000
25.5480	-0.0002	25.5464	-0.0001
25.5481	-0.0001	25.5465	0.0000

TABLE 4. - Resistance of thermometer No. 1586182 at the triple point of water (Con.)

5/28/64 Trans-Sonics triple point cell No. 2 - Physical Properties Section

Bridge Reading			
N	Deviation from Average	R	Deviation from Average
25.5481	-0.0001	25.5465	0.0000
25.5481	-0.0001	25.5464	-0.0001
25.5483	+0.0001	25.5468	+0.0003
25.5487	+0.0005	25.5470	+0.0005
25.5486	+0.0004	25.5468	+0.0003
25.5486	+0.0004	25.5469	+0.0004
25.5488	+0.0006	25.5470	+0.0005
25.5487	+0.0005	25.5470	+0.0005
25.5486	+0.0004	25.5469	+0.0004
25.5484	+0.0002	25.5467	+0.0002
25.5484	+0.0002	25.5468	+0.0003
25.5484	+0.0002	25.5467	+0.0002

6/1/64 Trans-Sonics triple point cell No. 2 - Physical Properties Section

Bridge Reading			
N	Deviation from Average	R	Deviation from Average
25.5488	+0.0006	25.5471	+0.0006
25.5488	+0.0006	25.5470	+0.0005
25.5487	+0.0005	25.5470	+0.0005
25.5486	+0.0004	25.5469	+0.0004
25.5484	+0.0002	25.5467	+0.0002
25.5482	0.0000	25.5465	0.0000
25.5482	0.0000	25.5465	0.0000